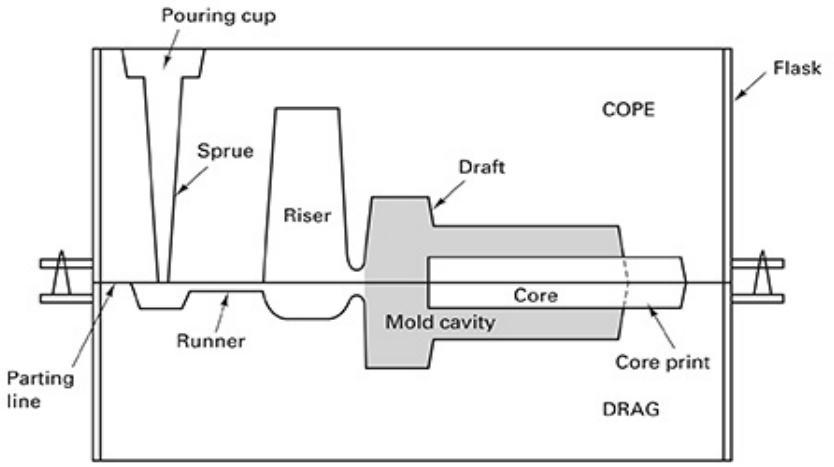
GATING SYSTEM DESIGN



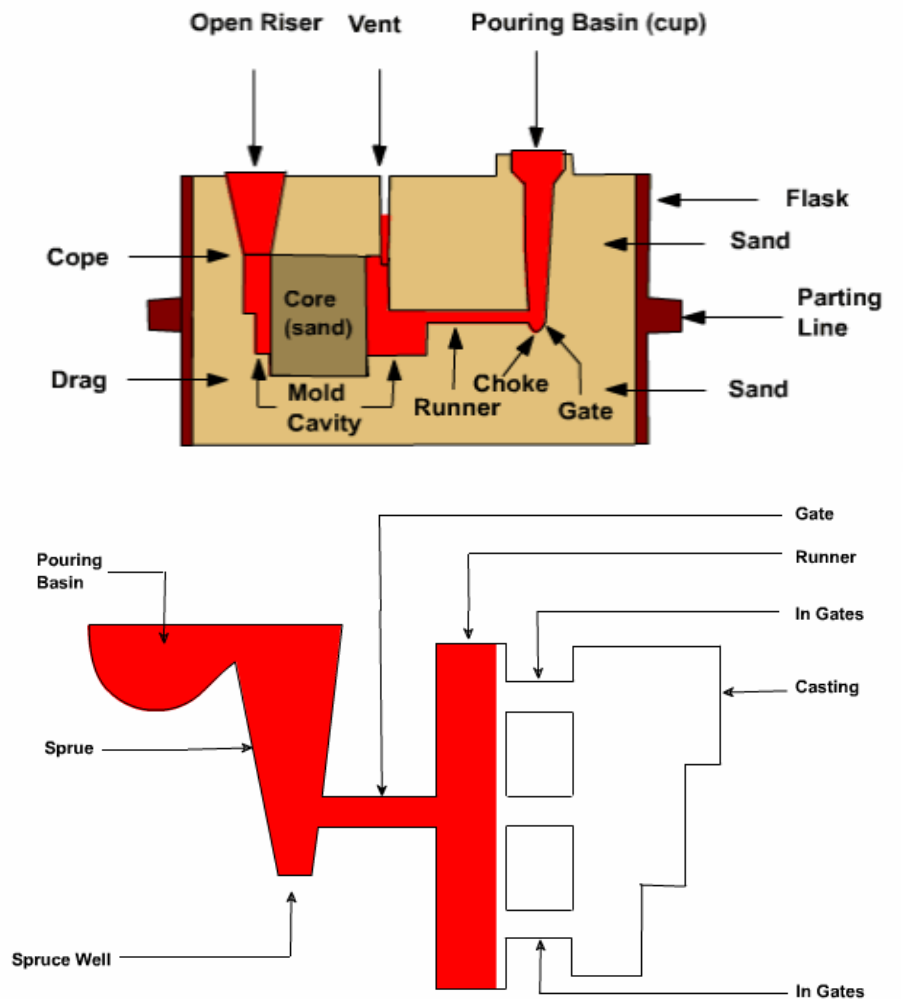


Figure 1: Gating systems

Elements of Gating System

The gating systems refer to all those elements which are connected with the flow of molten metal from the ladle to the mould cavity. The elements of gating systems are

- Pouring Basin
- Sprue
- Sprue Base Well
- Runner
- Runner Extension
- Ingate
- Riser

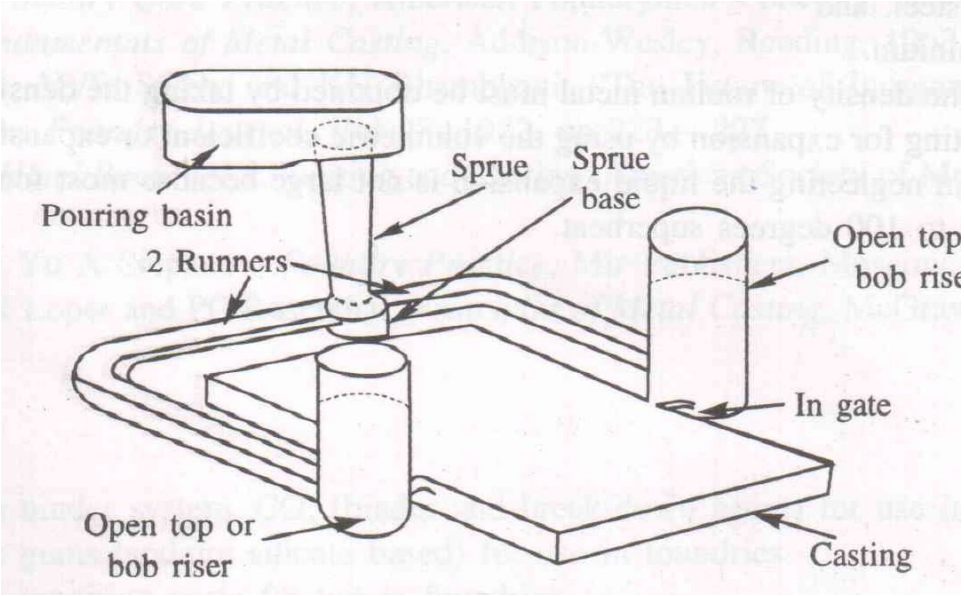


Figure 2: Components of a gating system

Any gating system designed should aim at providing a defect free casting. This can be achieved by considering following requirements.

- The mould should be completely filled in the smallest possible time without having to raise neither metal temperature nor use of higher metal heads.
- The metal should flow smoothly into the mould without any turbulence. A turbulence metal flow tends to form dross in the mould.
- Unwanted materials such as slag, dross and other mould materials should not be allowed to enter the mould cavity.
- The metal entry into the mould cavity should be properly controlled in such a way that aspiration of the atmospheric air is prevented.
- A proper thermal gradient should be maintained so that the casting is cooled without any shrinkage cavities or distortions.
- Metal flow should be maintained in such a way that no gating or mould erosion takes place.
- The gating system should ensure that enough molten metal reaches the mould cavity.
- It should be economical and easy to implement and remove after casting solidification.
- The casting yield should be maximised.

The liquid metal that runs through the various channels in the mould obeys the Bernoulli's theorem which states that the total energy head remains constant at any section. Ignoring frictional losses, we have

$$h + \frac{P}{\rho g} + \frac{v^2}{2g} = const.$$

Where h = Potential Head, m
P = Static Pressure, Pa
v = Liquid Velocity, m / s
$\rho g = w$ = Specific weight of liquid, N / m^2
g = Acceleration due to gravity, m / s^2

Though quantitatively Bernoulli's theorem may not be applied, it helps to understand qualitatively, the metal flow in the sand mould. As the metal enters the pouring basin, it has the highest potential energy with no kinetic or pressure energies. But as the metal moves through the gating system, a loss of energy occurs because of the friction between the molten metal and the mould walls. Heat is continuously lost through the mould material though it is not represented in the Bernoulli's equation.

Another law of fluid mechanics, which is useful in understanding the gating system behaviour, is the law of continuity which says that the volume of metal flowing at any section in the mould is constant. The same in equation form is

$$Q = A_1V_1 = A_2V_2$$

Where Q = Rate of flow, m^3 / s
A = Area of cross section, m^2
V = Velocity of metal flow, m / s

Pouring Time

The main objective for the gating system design is to fill the mould in the smallest time. The time for complete filling of a mould is called pouring time. Too long a pouring time requires a higher pouring temperature and too less a pouring time means turbulent flow in the mould which makes the casting defect prone. The pouring time depends on the casting materials, complexity of the casting, section thickness and casting size. Steels lose heat very fast , so required less pouring time while for non-ferrous materials longer pouring time is beneficial because they lose heat slowly and tend to form dross if metal is pour too quickly.

Ratio of surface area to volume of casting is important in addition to the mass of the casting. Also gating mass is considered when its mass is comparable to the mass of the casting.

- For grey cast iron up to 450 Kg

Pouring time, $t = K \{ 1.41 + \frac{T}{14.59} \} \sqrt{W}$ seconds

Where K = Fluidity of iron in inches / 40
T = Average section thickness, mm
W = Mass of the casting, Kg

- For grey cast iron greater than 450 Kg

Pouring time, $t = K \{ 1.236 + \frac{T}{16.65} \} \sqrt[3]{W}$ seconds

Typical pouring times for cast iron are

Casting mass	*Pouring time in seconds*
20 Kg	6 to 10
100 Kg	15 to 30

- Steel Casting

Pouring time, $t = (2.4335 - 0.3953 \log W) \sqrt{W}$ seconds

- Shell moulded ductile iron(vertical pouring)

Pouring time, $t = K_1 \sqrt{W}$ seconds

Where K_1 = 2.080 for thinner sections
= 2.670 for sections 10 to 25 mm thick
= 2.970 for heavier sections

- Copper alloy castings

Pouring time, $t = K_2 \sqrt[3]{W}$ seconds

Where K_2 is a constant whose value is given by 1.30 for top gating, 1.80 for bottom gating, 1.90 for brass and 2.80 for tin bronze.

Choke Area

After calculation of pouring time, it is required to establish the main control area which meters the metal flow into the mould cavity so that the mould is completely filled within the calculated pouring time. The controlling area is the choke area. The choke area happens to be at the bottom of the sprue and hence the first element to be designed in the gating system is the sprue size and its proportions. The main advantage in having sprue bottom as the choke area is that proper flow characteristics are established early in the mould.

The choke area can be calculated using Bernoulli's equation as

$$\mathbf{A} = \frac{W}{dtC\sqrt{2gH}}$$

Where A= Choke area, mm^2
W= Casting mass, Kg
t = Pouring time, s
d = Mass density of the molten metal, Kg / mm^3
g = acceleration due to gravity, mm /s^2
H = Effective metal head (sprue height), mm
C = Efficiency factor which is a function of the gating system used

The effective sprue height H , of the mould depends on the casting dimensions and type of the gating used. It can be calculated using the following relations.

Top gate, H= h **Bottom gate** $\mathbf{H = h - \frac{c}{2}}$ **and** $\mathbf{H = h - \frac{pxp}{2c}}$

Where h = Height of the sprue
p = Height of mould cavity in cope
c = Total height of the mould cavity

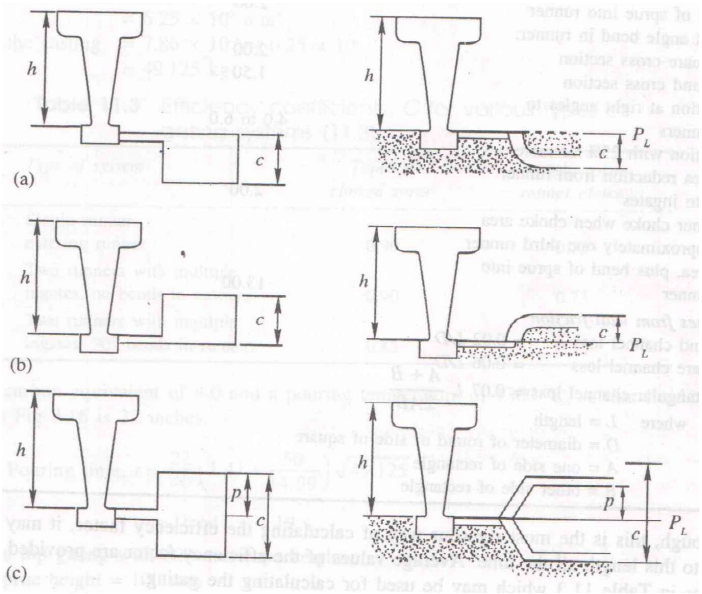


Figure 3: Effective sprue height

The efficiency coefficient of the gating system depends on the various sections that are normally used in a gating system. The elements of a gating system should be circular in cross section since they have lower surface area to volume ratio which would reduce heat loss and have less friction. Moreover, streamlining the various gating elements would greatly increase volumetric efficiency of the gating system and allow for smaller size gates and runners which would increase the casting yield. Whenever a runner changes direction or joins with another runner or gate, there is some loss in the metal head, all of which when taken properly into consideration would give the overall efficiency of the gating system.

Type of system	Tapered choked sprue	Straight sprue runner choke
Single runner	0.90	0.73
Two runners with multiple gates no bends in runners	0.90	0.73
Two runners with multiple gates 90^0 bends in runners	0.85	0.70

Table I: Efficiency coefficients, C for various types of gating systems

Sprue

The sprues should be tapered down to take into account the gain in velocity of the metal as it flows down reducing the air aspiration. The exact tapering can be obtained by equation of continuity. Denoting the top and the choke sections of the sprue by the subscripts t and c respectively, we get

$$\mathbf{A_t V_t = A_C V_C}$$

Or

$$\mathbf{A_t = A_C}\ \frac{V_c}{V_t}$$

Since the velocities are proportional to the square of the potential heads, then from Bernoulli's equation

$$\mathbf{A_t = A_C}\ \sqrt{\frac{h_c}{h_t}}$$

The square roots suggest that the profile of the sprue should be parabolic if exactly done as per the above equation. But making a parabolic sprue is inconvenient in practice and therefore a straight taper is preferable.

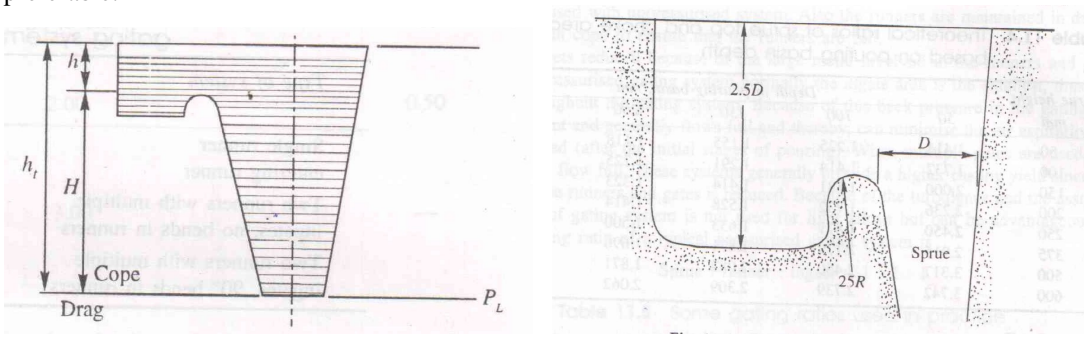


Figure 4: Sprue and pouring basin height and area

Sprue height, mm	Depth in pouring basin, mm				
	50	100	150	200	250
50	1.414	1.225	1.155	1.118	1.095
100	1.732	1.414	1.291	1.225	1.183
150	2.000	1.581	1.414	1.323	1.265
200	2.236	1.732	1.528	1.414	1.342
250	2.450	1.871	1.633	1.500	1.414
375	2.915	2.179	1.871	1.696	1.581
500	3.317	2.450	2.082	1.871	1.732
600	3.742	2.739	2.309	2.062	1.897

Table II: Theoretical ratios of sprue top and choke areas based on pouring basin depth

Other Gating Elements

Pouring Basin

The main function of a pouring basin is to reduce the momentum of the liquid flowing into the mould by settling first into it. In order that the metal enters into the sprue without any turbulence it is necessary that the pouring basin be deep enough, also the entrance into the sprue be a smooth radius of at least 25 mm. The pouring basin depth of 2.5 times the sprue entrance diameter is enough for smooth metal flow and to prevent vortex formation. In order that vortex is not formed during pouring, it is necessary that the pouring basin be kept full and constant conditions of flow are established. This can be achieved by using a delay screen or a strainer core. A delay screen is a small piece of perforated thin tin sheet placed in the pouring basin at the top of the down sprue. This screen usually melts because of the heat from the metal and in the process delays the entrance of metal into the sprue thus filling the pouring basin fully. This ensures a constant flow of metal as also exclude slag and dirt since only metal from below is allowed to go into the sprue. A similar effect is also achieved by a strainer core which is a ceramic coated screen with many holes. The strainer restricts the flow of metal into the sprue and thus helps in quick filling of the pouring basin. Pouring basins are most desirable for alloys which form troublesome oxide skins (aluminium, aluminium bronze, etc.)

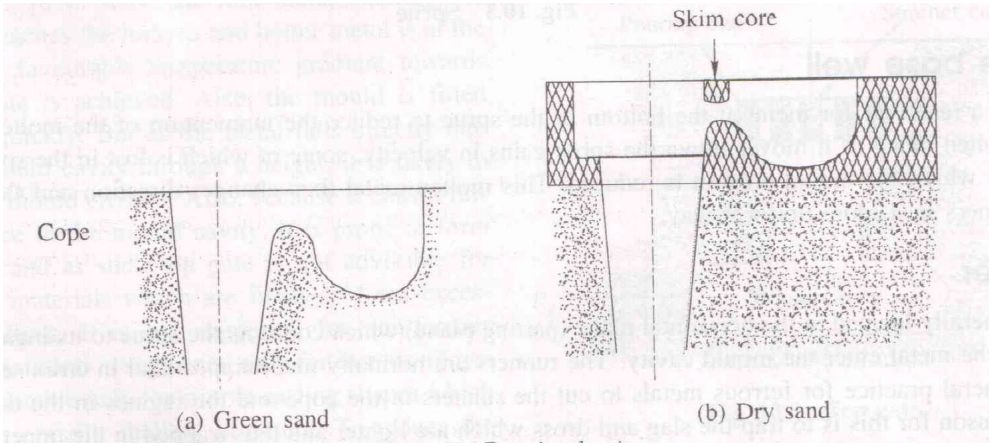


Figure 5: Pouring basin (1)

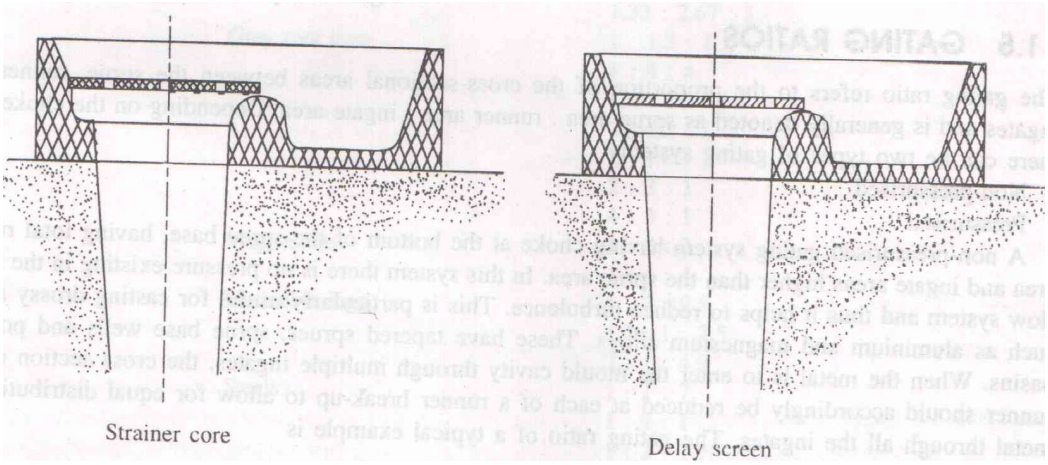


Figure 6: Pouring basin (2)

Sprue Base Well

The provision of a sprue base well at the bottom of the sprue helps in reducing the velocity of the incoming metal and also the mould erosion. A general guide line could be that the sprue base well area should be five times that of the sprue choke area and the well depth should be approximately equal to that of the runner.

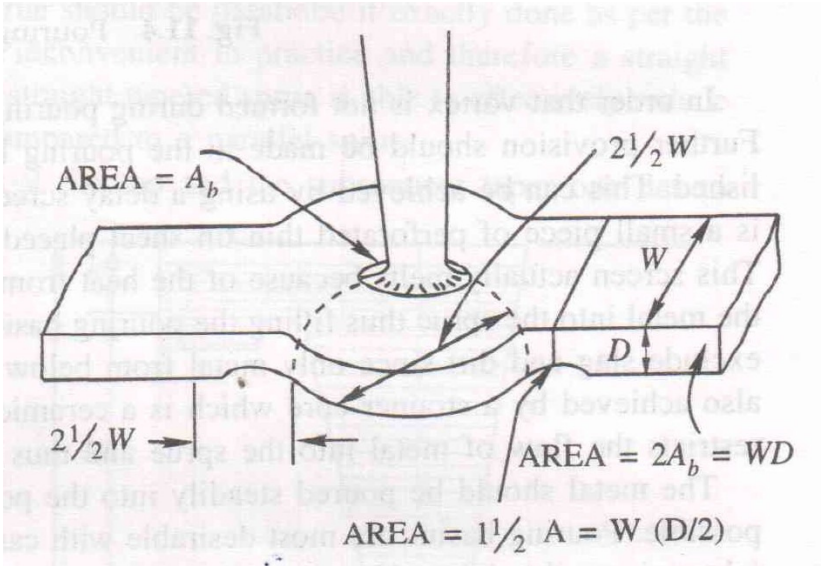


Figure 7: Sprue base well design

Gating Ratios

It refers to the proportion of the cross sectional areas between the sprue, runner and ingates and is generally denoted as sprue area : runner area : ingate area. Depending on the choke area there can be two types of gating systems:

- Non-pressurised
- Pressurised

A non –pressurised gating system having choke at the sprue base, has total runner area and ingate area higher than the sprue area. In this system there is no pressure existing in the metal flow system and thus it helps to reduce turbulence. This is particularly useful for casting drossy alloys such as aluminium alloys and magnesium alloys. When metal is to enter the mould cavity through multiple ingates, the cross section of the runner should accordingly be reduced at each of a runner break-up to allow for equal distribution of metal through all ingates. A typical gating ratio is **1:4:4**

The disadvantages of unpressurised gating are:

- The gating system needs to be carefully designed to see that all parts flow full. Otherwise some elements of the gating system may flow partially allowing for the air aspiration. Tapered sprues are invariably used with unpressurised system. The runners are maintained in drag while the gates are kept in cope to ensure that runners are full.
- Casting yield gets reduced because of large metal involved in the runners and gates.

In the case of pressurised gating system normally the ingates area is the smallest, thus maintaining a back pressure throughout and generally flows full and thereby, can minimize the air aspiration even when a straight sprue is used. It provided higher casting yield since the volume of metal used up in the runners and gates is reduced. Because of turbulence and associated dross formation, this type of gating system is not used for light alloys but can be advantageously used for ferrous castings. A typical gating ratio is **1:2:1**.

While designing the runner system, care should be taken to reduce sharp corners or sudden change of sections since they tend to cause turbulence and gas entrapment. Though from heat loss factor circular cross section runners are preferable, traditionally trapezoidal runner sections are employed to reduce the turbulence. The approximate proportions are fro a square to rectangle with width twice as that of the depth of the runner. When multiple ingates are used, the runner cross section should be suitably restricted at the separation of each runner in the interest of uniform flow through all sections.

It is a general practice to cut runner in the cope and the ingate in the drag to help in the trapping of the slag. Sometimes it is good to have half of the runner in the cope side and rest in the drag.

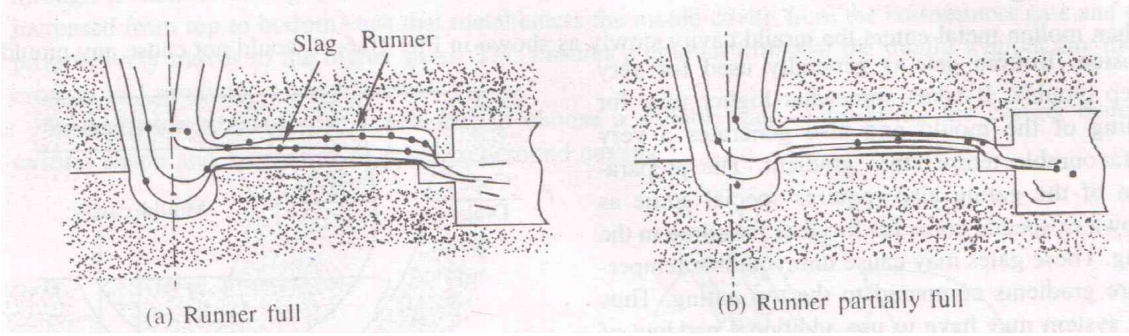


Figure 8: Runners

But for aluminium alloy castings, it is recommended that the runners be placed in the drag and the ingates in the cope so that dross (3.99 g/cm^2) which is heavier compared to aluminium (2.70 g/cmm^2) is restricted. Also the entry into runners from sprue base well should be made as smooth as possible in such castings, otherwise the direction of flow would tend to be turbulent and leads to drossing when any change abruptly occurs in the cross sectional areas.

Material	Gating Ratio
Aluminium	1:2:1, 1:1.2:2, 1:2:4, 1:3:3, 1:4:4, 1:6:6
Aluminium bronze	1: 2.88:4.8
Brass	1:1:1, 1:1:3, 1.6:1.3:1
Copper	2:8:1, 3:9:1
Ductile iron	1.15:1.1:1, 1.25:1.13:1, 1.33:2.67:1
Grey cast iron	1:1.3:1, 1:4:4, 1.4:1.2:1, 2:1.5:1, 2:1.8:1, 2:3:1, 4:3:1
Magnesium	1:2:2, 1:4:4
Malleable iron	1:2:9.5, 1.5:1:2.5, 2:1:4.9
Steels	1:1:7, 1:2:1, 1:2:1.5, 1;2:2, 1:3:3, 1.6:1.3:1

Table III: Some gating ratios used in practice

Ingate

The ingate can be considered as a weir with no reduction in cross section of the stream at the gate. Then the rate of flow of molten metal through the gates depends on the free height of the metal in the runner and the gate area & the velocity with which metal is flowing in the runner. The free height, h can be calculated as

$$h = 1.6 \sqrt[3]{\frac{QxQ}{gxbxb}} + \frac{VxV}{2g} \text{ mm}$$

Where Q = metal flow rate, mm^3/s
b = gate width, mm
V = metal velocity in runner, mm/s
g = acceleration due to gravity, mm/s^2

Having obtained the head of metal, the height of the gate h, is given by

$$h_1 = h - 5 \text{ mm}$$

Gates higher than this will not fill completely and those lower than this will increase the velocities of the stream entering into. The ingates are generally made wider compared to depth, up to a ratio of 4. This facilitates in the severing of the gates from the casting after solidification. It may sometimes preferable to reduce the actual connection between the ingate and the casting by means of a neck-down so that the removal of it is simplified. The following points should be kept in mind while choosing the positioning of the ingates.

- Ingate should not be located near a protruding part of the mould to avoid the striking of vertical mould walls by molten metal stream.
- Ingates should be preferably be placed along the longitudinal axis of the mould wall.
- It should not be placed near a core print or a chill.
- Ingate cross sectional area should preferably be smaller than the smallest thickness of the casting so that the ingates solidify first and isolate the casting from the gating system. This would reduce the possibility of air aspiration through gating system in case of metal shrinkage.
- It is possible that the farthest gate from the sprue is likely to flow more metal than others, particularly in the case of unpressurised system. To make for more uniform flow through all the gates, the runner area should be reduced progressively after each ingate, such that restriction on the metal flow would be provided.

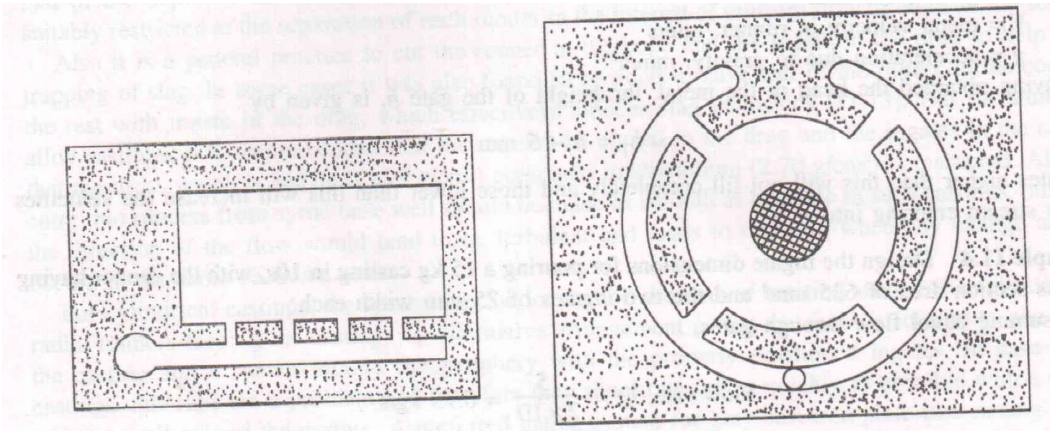


Figure 9: Multiple ingates feeding the various parts of a casting

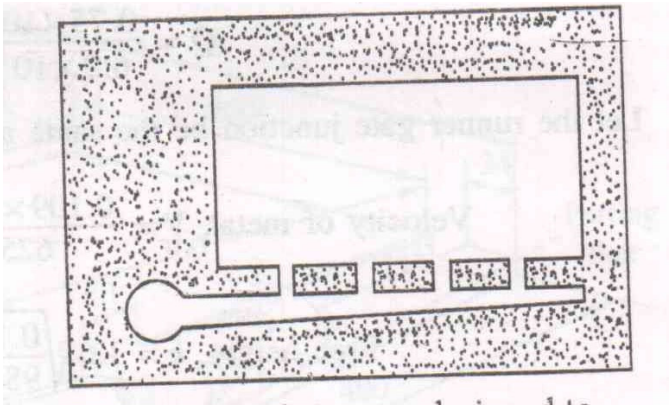


Figure 10: Multiple ingates designed to induce uniform flow through all gates

Slag Trap Systems

In order to obtain sound casting quality, it is essential that the slag and other impurities be removed from the molten metal fully before it enters the mould cavity. Apart from the use of pouring basins and strainer cores the following methods are also used.

Runner Extension: Normally the metal which moves first into the gating system is likely to contain slag and dross which should not be allowed to get into the mould cavity. This could be achieved by extending the runner beyond the ingates so that the momentum of the metal will carry it past the gates and to a blind alley called runner extension. A runner extension having a minimum of twice the runner width is desirable.

Whirl Gate: Another method employed successfully to trap the slag from entering steel casting is a whirl gate. This utilizes the principle of centrifugal action to throw the dense metal to the periphery and retain the lighter slag at the centre. In order to achieve this action, it is necessary that entry area should be at least 1.5 times the exit area so that the metal is built up at the centre quickly. Also the metal should revolve 270^0 before reaching the exit gate so as to gain enough time for separating the impurities.

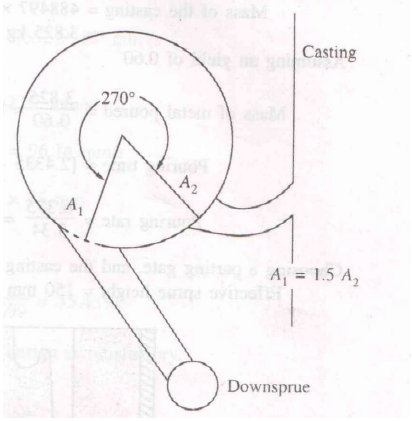


Figure 11: Whirl gate

Design of Riser

The function of a riser (also called reservoir, feeders, or headers) is to feed the casting during solidification so that no shrinkage cavities are formed. The requirement of risers depends to a great extent upon the type of metal poured and the complexity of the casting. Let us consider the mould of a cube which is filled with liquid metal. As time progresses, the metal starts losing heat through all sides and as a result starts freezing from all sides equally trapping the liquid metal inside. But further solidification and subsequent volumetric shrinkage and the metal contraction due to change in temperature causes formation of a void. The solidification when complete, finally results in the shrinkage cavity as shown in the figure. The reason for the formation of the void in the cube casting is that the liquid metal in the centre which solidifies in the end is not fed during the solidification; hence the liquid shrinkage ends up as a void. Such isolated spots which remain hot till the end are called *hot spots*.

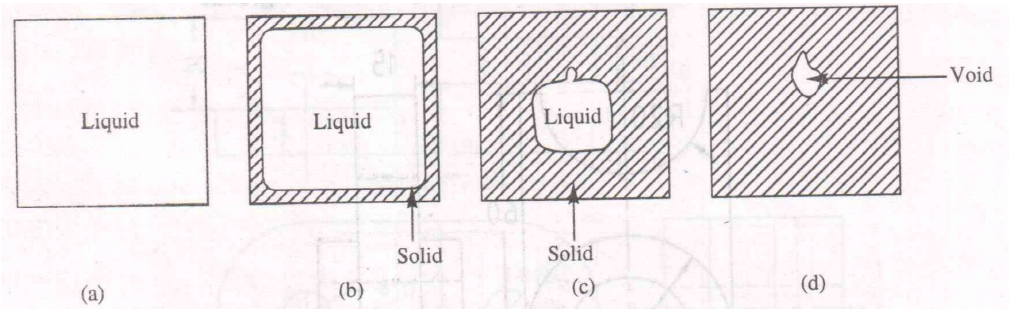


Figure 12: Solidification of cube casting

Functions of Risers

- Provide extra metal to compensate for the volumetric shrinkage
- Allow mold gases to escape
- Provide extra metal pressure on the solidifying metal to reproduce mold details more exactly.
- To compensate mould expansion during pouring of hot liquid metal because of soft mould.

It is the task of casting designer to reduce all hot spots so that no shrinkage cavities occurred. Since solidification of the casting occurs by loosing heat from the surfaces and the amount of the heat is given by the volume of the casting, the cooling characteristics of a casting can be represented by the surface area to the volume ratio. Since the riser is almost similar to the casting in its solidification behaviour, the riser characteristics can also be specified by the ratio of its surface area to volume. If this ratio of casting is higher, then it is expected to cool faster.

According to Chvorinov, solidification time can be calculated as

$$t_s = K \{ \frac{V}{SA} \}^2$$

Where t_s = solidification time, s
V = volume of the casting,
SA = surface area
K = mould constant which depends on pouring temperature, casting & mould thermal Characteristics

The freezing ratio, **X** of a mould is defined as the ratio of cooling characteristics of casting to that of the riser.

$$\mathbf{X} = \frac{\text{SAcasting / Vcasting}}{\text{SAriser / Vriser}}$$

In order to feed the casting, the riser should solidify last and hence its freezing ratio should be greater than unity.

CAINE's Method

$$\mathbf{X = \{ a / Y\text{-}b \} + c}$$

Where Y = riser volume / casting volume
a, b, c are constants whose values for different materials are given here.

Material	a	b	c
Steel	0.10	0.03	1.00
Aluminium	0.10	0.06	1.08
Cast iron, Brass	0.04	0.017	1.00
Grey cast iron	0.33	0.030	1.00
Aluminium bronze	0.24	0.017	1.00
Silicon bronze	0.24	0.017	1.00

Table IV: Values of a,b,c for different materials

Design Requirements of Risers

1. Riser size: For a sound casting riser must be last to freeze. The ratio of (volume / surface area)^2 of the riser must be greater than that of the casting. However, when this condition does not meet, the metal in the riser can be kept in liquid state by heating it externally or using exothermic materials in the risers.
2. Riser placement: the spacing of risers in the casting must be considered by effectively calculating the feeding distance of the risers.
3. Riser shape: cylindrical risers are recommended for most of the castings as spherical risers, although considers as best, are difficult to cast. To increase volume/surface area ratio the bottom of the riser can be shaped as hemisphere.

Reference:
1. Manufacturing Technology by P.N.Rao, TMH, page126 to 179